

# **BluTilt User Manual**

YieldPoint Inc

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## Specification

**BluTilt** is a full 360 arcdeg triaxial tiltmeter for very precise measurement (0.001 arcdeg resolution) of changes in inclination.

Since the **BluTilt** features full tri-axial measurement, attachment on structures does not require precise leveling. The **BluTilt** can be attached to a beam or mounted directly to any structure. The **BluTilt** is also available in borehole model (shown) with a 38mm OD.

The **BluTilt** has an internal logging capability that can store 30,000 readings. The results are downloaded over BLE 4.2 or Bluetooth 5 to an Android device. The reading interval and clock synchronization are also configured via Bluetooth using YieldPoint's free BluPoint App.

The BluTilt is available in several different types of package including being incorporated in a tilt beam.



## Generalized 3-D Rotation

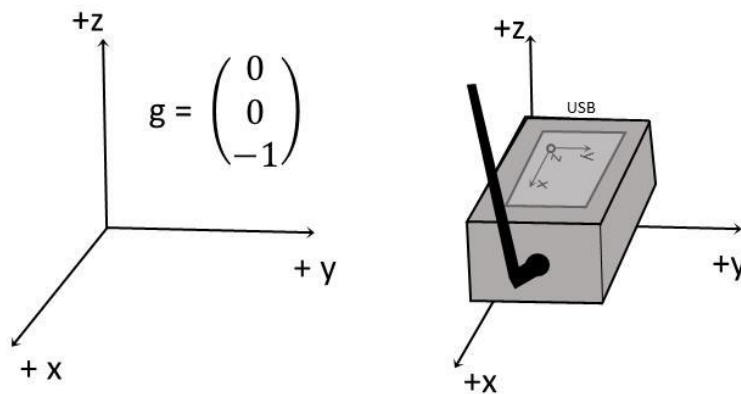
An accelerometer measures the orientation with respect to the gravity vector which for a cartesian coordinate system (Fig 1) is given by :

$$g = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} \dots\dots\dots(1)$$

The measured acceleration values are given by

$$a = R \cdot g \dots\dots\dots(2)$$

where R is a generalized rotation matrix recognizing that the coordinate system is right handed.



**Figure 1:** Right handed coordinate system

As explained in NXP application note AN3461, 3-D changes in tilt can be described by rotations around each of the three axes according to:

$$R_x(X) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos X & \sin X \\ 0 & -\sin X & \cos X \end{pmatrix} \dots\dots(3)$$

$$R_y(Y) = \begin{pmatrix} \cos Y & 0 & -\sin Y \\ 0 & 1 & 0 \\ \sin Y & 0 & \cos Y \end{pmatrix} \dots\dots(4)$$

$$R_z(Z) = \begin{pmatrix} \cos Z & \sin Z & 0 \\ -\sin Z & \cos Z & 0 \\ 0 & 0 & 1 \end{pmatrix} \dots\dots(5)$$

These are commonly referred to as pitch, roll and yaw. By convention, and because the rotation do not commute, general rotation are conventionally applied in a pitch, then roll, then yaw sequence,  $R_{xyz}$ .

Two important points arise from the above equations.

1.  $a_z = R_z(Z)$ .  $g$  does not vary with changes in  $R_z$ . In other words, yaw cannot be measured by an accelerometer and would require a compass.
2. There are two possible sequences in which the remaining two rotations ( $R_x$  and  $R_y$ ) can be applied and since the composite rotations do not commute (i.e. the order in which the rotations are applied affects the final result) an  $R_{xy}$  (**pitch is applied first, then roll**) **convention is typically adopted.**

## Installation

The BluTilt uses a 3-axis accelerometer to measure the orientation of the gravity vector  $g$  [0,0,- $g$ ]. As stated above, this does not mean that the device can measure complete 3-D rotations (pitch, roll and yaw) because rotations in the horizontal plane (yaw) cannot be resolved with respect to the vertical gravitational vector. However, the user can install the BluTilt on a structure in any orientation while maintaining resolution and accuracy.

**Important: The BluTilt is capable of measuring pitch and roll only, but allows the device to be mounted in any orientation.**

## Reporting Modes for BluTilt

The BluTilt can be configured in several different reporting modes depending on the application.

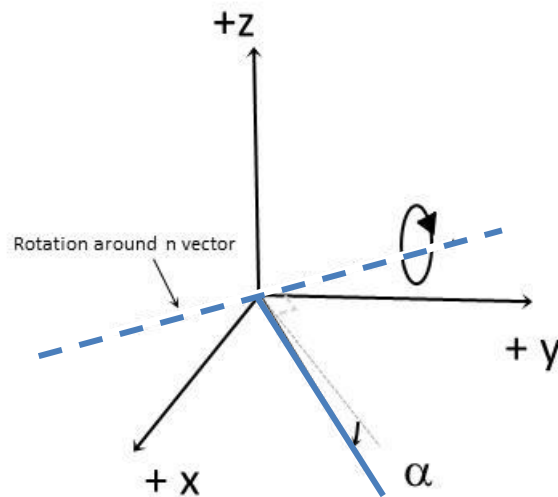
		Output CSV values					
		Channel Number					Tilt_mode
Mode Desc	Tilt_mode	Temp	1	2	3	4	5
Raw	Mode 0	$T^o$	$a_x$	$a_y$	$a_z$	-	0
Vector	Mode 1	$T^o$	$\alpha$	$n_x$	$n_y$	$n_z$	1
2-angle	Mode 2	$T^o$	$X$	$Y$	-	<b>tilt_z_up</b>	2
3-angle	Mode 3	$T^o$	$\varphi$	$\theta$	$\psi$	-	3

## tilt\_mode 0 - Raw data:

The raw data from the accelerometer is a 20-bit result varying from 256,000 (+1g) to -256,000(-1g). The acceleration values for the three axes, x, y and z are reported.

## tilt\_mode 1 - Vector mode:

Another way to define a tilt is to specify (i) a single tilt angle ( $\alpha$ ) combined with (ii) a vector ( $n$ ) representing the axis of rotation (see NXP app note section 4). This calculation avoids problems related to instability and singularities in the trigonometric functions.



**Figure 2:** Vector mode involves one angle ( $\alpha$ ) and the axis of rotation ( $n$ )

Simple vector algebra provides the means to determine the difference between two tilt readings, for example an initial reference 3-D accelerometer readings ( $\mathbf{a}^0$ ) and a current reading( $\mathbf{a}$ ). The scalar product  $\mathbf{a} \cdot \mathbf{a}^0$  gives the angle ( $\alpha$ ) between the two vectors

$$\mathbf{a} \cdot \mathbf{a}^0 = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \cdot \begin{pmatrix} a_x^0 \\ a_y^0 \\ a_z^0 \end{pmatrix} = a_x a_x^0 + a_y a_y^0 + a_z a_z^0 = |\mathbf{a}| |\mathbf{a}^0| \cos \alpha \quad (6)$$

or rearranging:

$$\cos \alpha = \frac{a_x a_x^0 + a_y a_y^0 + a_z a_z^0}{\sqrt{a_x^2 + a_y^2 + a_z^2} \sqrt{a_x^{02} + a_y^{02} + a_z^{02}}} \quad (7)$$

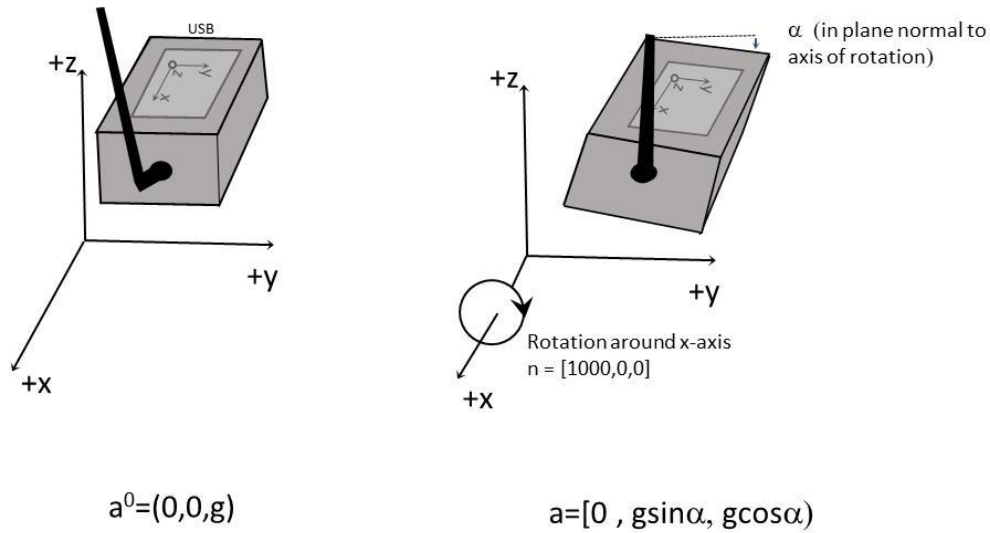
The unit vector  $\mathbf{n}$  (the axis of rotation) is normal to both  $\mathbf{a}$  and  $\mathbf{a}^0$ , such that  $\mathbf{a}$ ,  $\mathbf{a}^0$  and  $\mathbf{n}$  form a right handed triplet.

$$\mathbf{a} \times \mathbf{a}^0 = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \times \begin{pmatrix} a_x^0 \\ a_y^0 \\ a_z^0 \end{pmatrix} = |\mathbf{a}| |\mathbf{a}^0| \mathbf{n} \sin \alpha \quad (8)$$

or

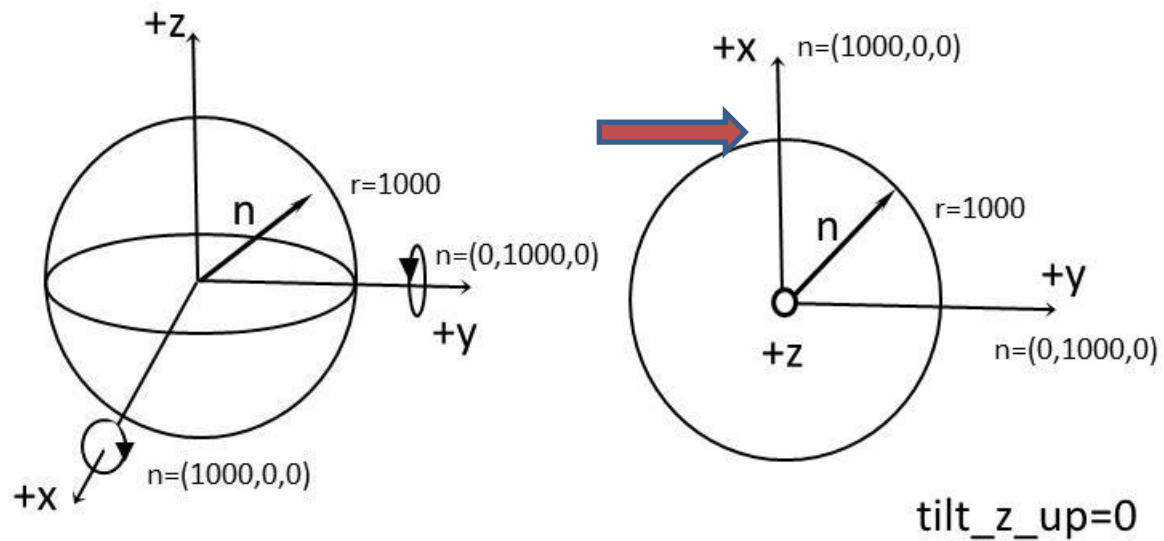
$$\mathbf{n} \sin \alpha = \left( \frac{1}{\sqrt{a_x^2 + a_y^2 + a_z^2}} \right) \left( \frac{1}{\sqrt{b_x^2 + b_y^2 + b_z^2}} \right) \begin{pmatrix} a_y b_z - a_z b_y \\ a_z b_x - a_x b_z \\ a_x b_y - a_y b_x \end{pmatrix} \quad (9)$$

**Note:** The default reference vector ( $\mathbf{a}^0$ ) is (0,0,1) or z-axis up. From equation 4, with this setting the z-component of  $\mathbf{n}$  is **always zero** ( $a_x b_y - a_y b_x = 0$ ). Physically this means that the axis of rotation lies in the horizontal plane.

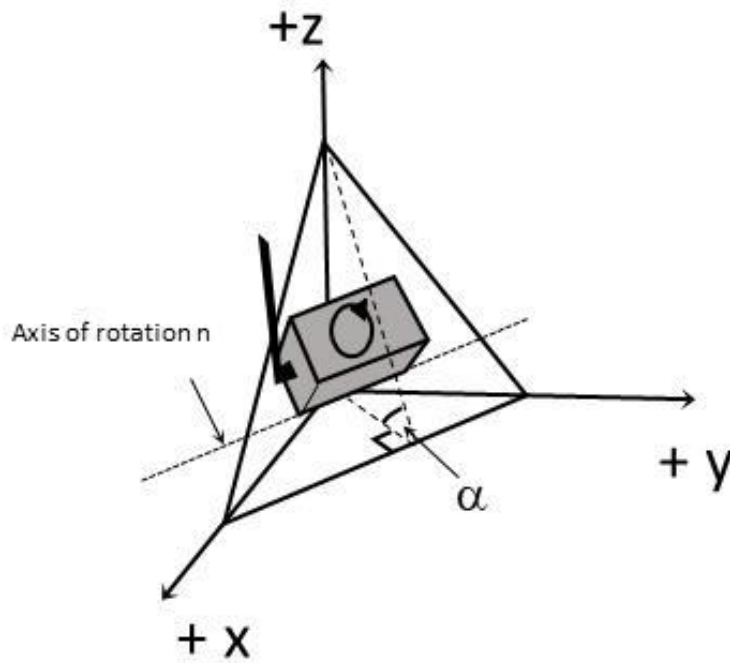


**Figure 3:** An example for tilt\_mode 1 with the default reference ( $\mathbf{a}^0 = [0, 0, 1]$ ) and rotation around the x-axis (1000,0,0).

The axis of rotation is described by a vector of length 1000 the end of which lies on a spherical surface for all possible orientations. Note: the 1000 multiplier is applied to the  $n$  vector to preserve precision.



**Figure 4:** The axis of rotation vector for tilt\_mode 1. LHS:  $n$  vector of length 1000, the end of which describes a spherical surface. RHS The default reference value  $a^0$  is  $(0,0,1)$  (tilt\_z\_up 0) so that the axis of rotation lies in the horizontal plane.



**Figure 5:** The advantage of tilt\_mode 1. The angle of tilt remains constant and equal to  $\alpha$  even if the BluTilt spins on the plane as indicated. Hence **this single tilt value ( $\alpha$ ) provides the best option for alarms.**

### ***Setting a user defined reference ( $a^0$ )***

In many situations the user will want to monitor changes in tilt from an arbitrary reference following installation. To set a reference tilt ( $a^0$ ) the user should install the Blutilt and allow time for the installation to stabilize. The custom command **tilt\_ref\_set** will save the current tilt reading ( $a^0$ ) to non-volatile memory and all future tilt readings will be changes relative to  $a^0$ .

The operating values for  $a^0$  can be extracted using the custom command **tilt\_ref**.



## tilt\_mode 2 - 2 angle mode

Assuming that the rotation sequence is applied using  $R_{xy}$  and that  $R_z=0$ , as explained in AN3461 the change in orientation of the BluTilt can be described by changes from the horizontal plane of two orthogonal horizontal axes that may be referred to as pitch ( $\phi_{xy}$ ) and roll ( $\theta_{xy}$ ). Conceptually this is similar to the response from a biaxial tiltmeter configured to measure changes in tilt from the horizontal plane.

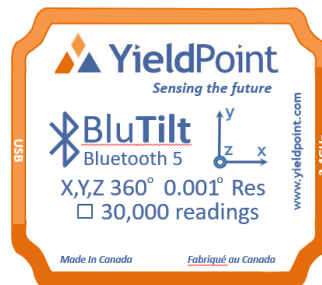
The solution for  $\phi_{xy}$  and  $\theta_{xy}$  from a set of triaxial acceleration values ( $a_x, a_y, a_z$ ) can be written as:

$$\phi_{xy} = \tan^{-1} \left( \frac{a_y}{a_z} \right) \dots\dots\dots(10)$$

$$\theta_{xy} = \tan^{-1} \left( \frac{-a_x}{\sqrt{a_y^2 + a_z^2}} \right) \dots\dots\dots(11)$$

For the purposes of geotechnical engineering where the structure is essentially static, it is more appropriate to reference the two angle solution to the orientation of the BluTilt itself, as shown by the label on the cover, which depends on how it was installed in the field.

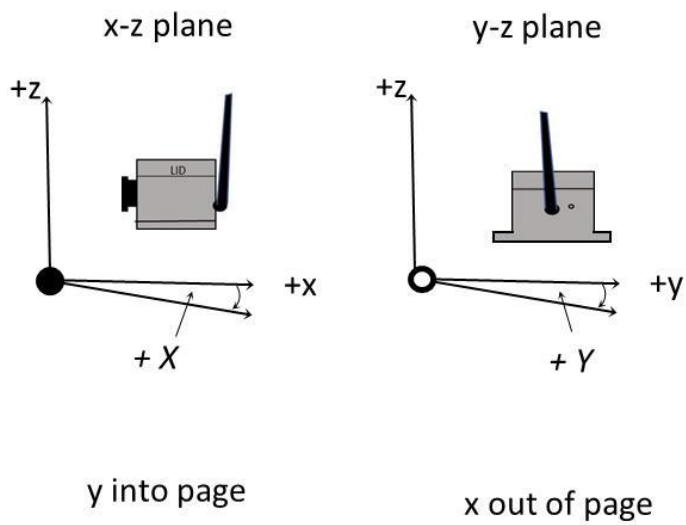
**Important: When the lid is removed to replace batteries make sure it is replaced correctly (2.4GHz should line up with the antenna).**



For tilt\_mode 2, the most accurate operation is when one of the axes is oriented either straight-up or straight down. For any installation configuration, this corresponds to six orientations each of which can be configured using the custom command *tilt\_z\_up* as will be explained below.

The data payload is populated by the two angles corresponding to pitch and roll. For clarity these are remapped as X, Y, Z along the x, y and z axes of the BluTilt. The sign is positive for downward rotation from the positive end of the axis. Field 5 of the output string is the *tilt\_z\_up* value and field 6 is the *tilt\_mode* value

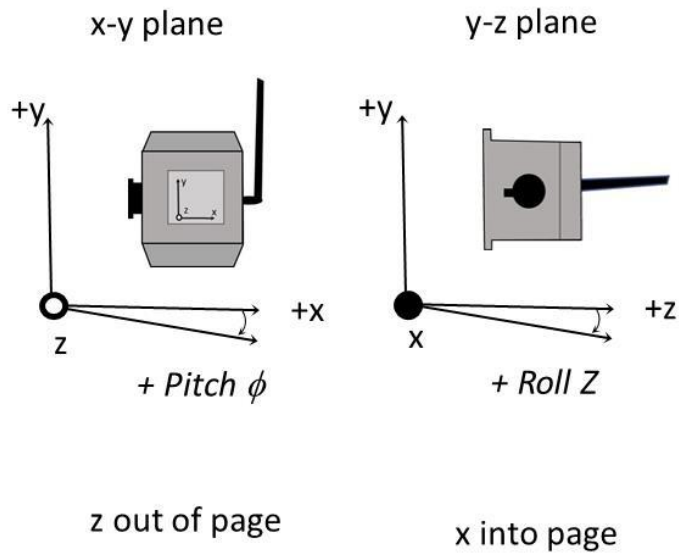
**tilt\_z\_up = 0    +z is up**



**Output Channels:**

1	2	3	4	5	6
T	X	Y	0	0	2

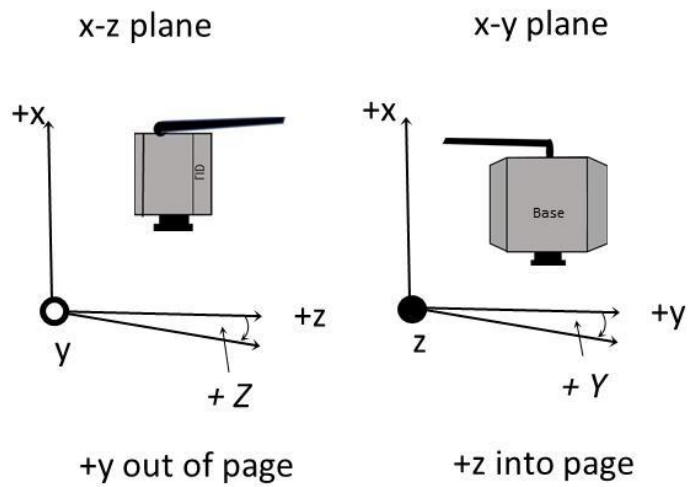
**tilt\_z\_up = 1    +y is up**



**Output Channels:**

1	2	3	4	5	6
T	X	0	Z	1	2

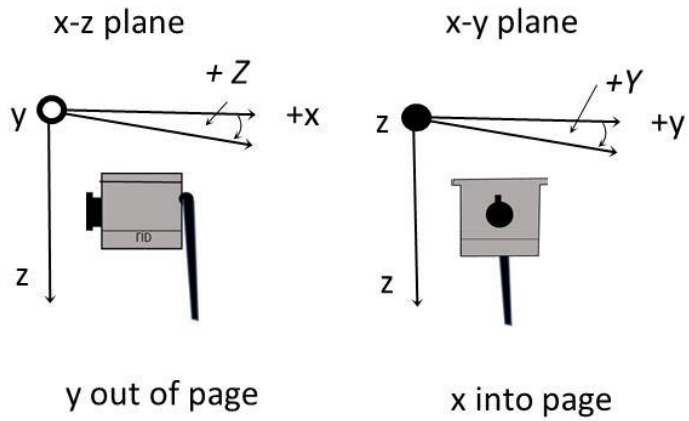
**tilt\_z\_up = 2    +x is up**



**Output Channels:**

1	2	3	4	5	6
T	0	Y	Z	2	2

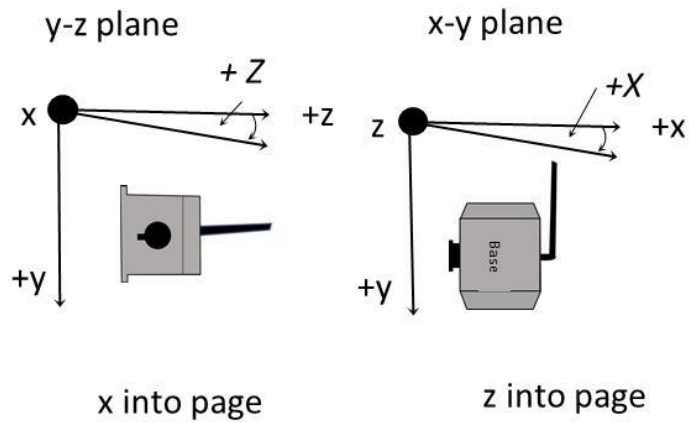
**tilt\_z\_up = 3    +z is down**



**Output Channels:**

1	2	3	4	5	6
T	X	Y	0	3	2

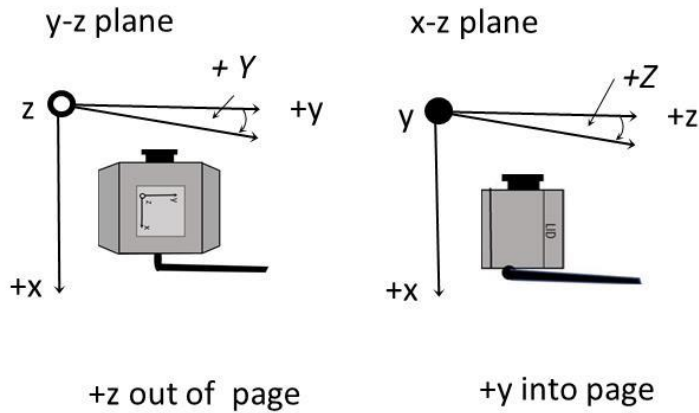
**tilt\_z\_up = 4    +y is down**



**Output Channels:**

1	2	3	4	5	6
T	X	Y	0	4	2

**tilt\_z\_up = 5    +x is down**



### Output Channels:

1	2	3	4	5	6
T	0	Y	Z	5	2

### Tilt\_mode 3: Three angles.

The ‘three angle’ mode uses the scheme presented in AN 1057 from Analog Devices Inc (ADI).

The values vary from  $-180^\circ$  to  $+180^\circ$  according to the following formulae:

$$\phi = \tan^{-1} \left( \frac{a_x}{\sqrt{a_y^2 + a_z^2}} \right)$$

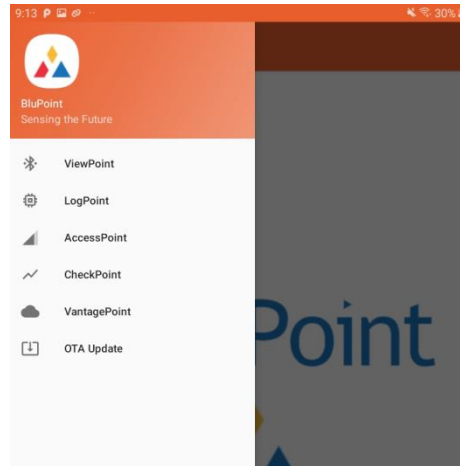
$$\theta = \tan^{-1} \left( \frac{a_y}{\sqrt{a_x^2 + a_z^2}} \right)$$

$$\psi = \tan^{-1} \left( \frac{\sqrt{a_x^2 + a_y^2}}{a_z} \right)$$

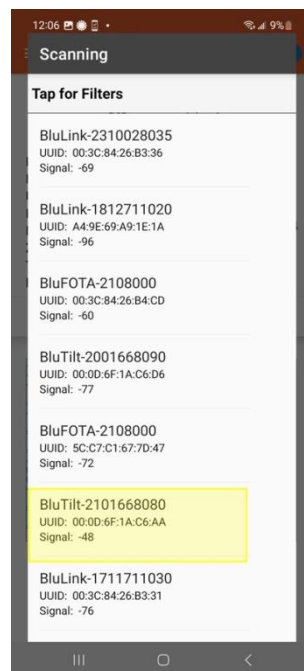
When the BluTilt is aligned with z-up the three angles are zero.

# How to Setup the BluTilt using the BluPoint App.

## Step 1: Connect to the BluTilt in ViewPoint

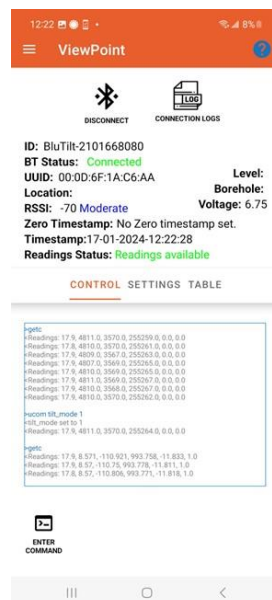
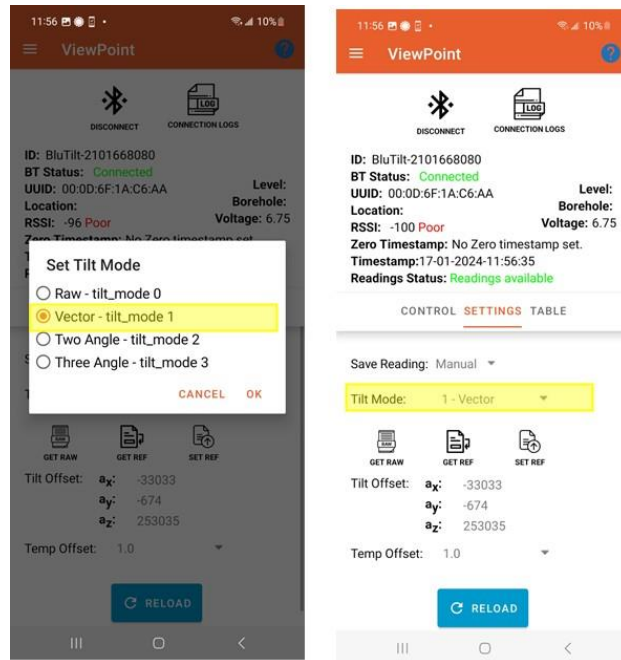


Open the ViewPoint Activity and connect to the BluTilt of interest. In the case 210166808 (YYMM66###). BluTilt will always have a **sensor\_type** = 66



## Step 2: From the SETTINGS Tab change the Tilt\_mode

From the tilt\_mode dropdown select Vector – tilt\_mode=1.



Raw readings,  $T$ ,  $a_x$ ,  $a_y$ ,  $a_z$


Vector mode change

Vector readings:  $T$ ,  $\alpha$ ,  $n_x$ ,  $n_y$ ,  $n_z$


For tilt-mode 1 a new reference plane can be set using SET REF.

Save Reading: Manual ▼


Tilt Mode: 1 - Vector ▼



GET RAW




GET REF



SET REF

Tilt Offset:  $a_x$ : -33033  
 $a_y$ : -674  
 $a_z$ : 253035

Temp Offset: 1.0 ▼

 RELOAD

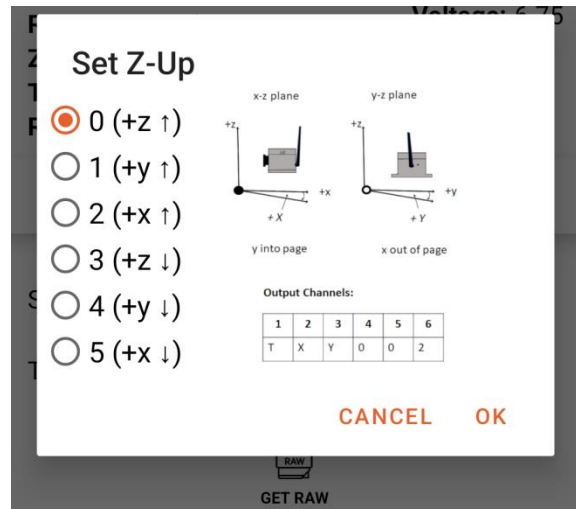
The angle,  $\alpha$ , will become close to zero. Note: when the angle of rotation ( $\mathbf{n}$  vector) is close to zero the axis of rotation may be quite variable.

For *tilt\_mode 2 – Two Angle mode*

<pre> &gt;ucom tilt_mode &lt;tilt_mode=1  &gt;getc &lt;Readings: 18.0, 8.577, -110.037, 993.858, -11.717, 1.0 &lt;Readings: 18.0, 8.576, -110.041, 993.857, -11.718, 1.0  &gt;ucom tilt_mode 2 &lt;tilt_mode set to 2 &lt;Readings: 17.9, 8.577, -110.087, 993.852, -11.724, 1.0           </pre>	<p>Vector readings: <math>T, \alpha, n_x, n_y, n_z</math></p> <p>Two Angle mode change</p> <p>Two angle readings: <math>T, X, Y</math></p>
---	--

After changing to Two Angle mode tilt\_mode 2 make sure the z-up setting is correct:





The two angles (tilt\_mode 2) are returned.

```
<Readings: 18.0, 8.55, -109.309, 993.939, -11.622, 1.0
<Readings: 17.9, 8.55, -109.309, 993.939, -11.622, 1.0
<Readings: 17.8, 8.549, -109.315, 993.939, -11.623, 1.0
<Readings: 17.9, 8.55, -109.281, 993.942, -11.618, 1.0
<Readings: 17.9, 8.55, -109.283, 993.942, -11.619, 1.0
<Readings: 17.9, 8.549, -109.295, 993.941, -11.62, 1.0
<Readings: 17.9, 8.549, -109.346, 993.935, -11.627, 1.0

>ucom tilt_mode 2
<tilt_mode set to 2
<Readings: 17.9, 8.549, -109.238, 993.947, -11.613, 1.0

>getc
<Readings: 17.9, -1.061, -0.786, 0.0, 0.0, 2.0
<Readings: 17.9, -1.061, -0.786, 0.0, 0.0, 2.0
<Readings: 18.0, -1.061, -0.786, 0.0, 0.0, 2.0
<Readings: 17.9, -1.06, -0.786, 0.0, 0.0, 2.0
<Readings: 17.9, -1.06, -0.785, 0.0, 0.0, 2.0
```

tilt\_mode 1

tilt\_mode 2

The final csv for each Reading is the tilt\_mode.

The settings for the BluTilt are applied using the LogPoint component. The results can be observed using the ViewPoint Component.

### Custom Commands for BluTilt.

Each command must be preceded by **ucom** followed with a space.

**tilt** -> print raw tilt values for calibration

**temp** -> print temperature offset

**temp 50** -> set temperature offset

**tilt\_ref** -> print reference reading for vector product

**tilt\_ref\_set** -> set current position as reference reading for vector product

**tilt\_z\_up** -> print set tilt orientation

**tilt\_z\_up 2** -> set tilt orientation 0 to 6

**tilt\_mode** -> print tilt mode, 0=raw, 1=vector, 2=two angle, 3=three angle

**tilt\_mode 2** -> set tilt mode

**tilt\_gain** -> print gain calibration constant for each axis

**tilt\_gain 1 1.0025** -> set gain calibration constant on axis 1 (0=x,1=y,2=z)

**tilt\_offset** -> print offset calibration constant for each axis

**tilt\_offset 1 2500** -> set offset calibration constant on axis 1

## Installing a YieldPoint BluTilt – Smooth Concrete Surface

The BluTilt will be installed using 4 Tapcon® screws

**Step 1:** Select the appropriate Tapcon® screw: Standard or Stainless Steel.

### ***Note: Standard vs. Stainless Steel Concrete Screws***

*The standard blue Tapcon® is suitable for use in indoor applications where moisture is not present. Standard blue Tapcon® s are coated with a blue Climaseal® coating that provides good rust resistant. The stainless steel screw is made from a 410 stainless steel and is coated with a silver Climaseal® designed for applications where added rust resistance is required.*

**Step 2:** Using a hammer drill and a carbide tipped masonry bit meeting ANSI standards, drill four (4) holes of the correct diameter required for the diameter of the screw that is being installed.

**Note: Diameter of Hole**

*Hole diameter is critical when installing Tapcon® s. The tolerance between the hole diameter and the diameter of the Tapcon® screw being used is very tight and any variations will affect the holding values. Each diameter of concrete screw has a specific diameter carbide drill bit that must be used for installation. The 3/16" diameter screw requires a 5/32" hole and the 1/4" requires a 3/16" hole. The hole must be drilled using a hammer drill with a carbide tipped bit meeting ANSI standards. A bit that meets ANSI standards will ensure that the hole diameter will meet the requirements of the Tapcon®.*

**Note: Depth of Hole**

*The depth of the hole that a Tapcon® concrete screw will be installed into is critical. The hole must be drilled 1/4" deeper than the screw will penetrate. This extra space at the bottom of the hole allows for an area for the dust created during the tapping process to fall without impacting installation. If enough space is not created during the drilling process, space may fill up with dust. The concrete screw taps threads into the base material and the screw could bottom out and prevent full installation. This situation may also lead the concrete screw to become bound in the hole and unable to be removed or inserted deeper.*

**Step3:** With a wire brush, compressed air or vacuum clean out the hole of all dust created during the drilling process.

**Step 4:** Coat the base of the BluTilt enclosure with either a structural adhesive or silicone.

**Step 5:** Use 4 Tapcon® screws either 1.5" or 2" long, to tightly secure the BluTilt. Align the hole in the fixture over the hole in the base material. Insert the concrete screw through a hole in the fixture and into the hole in the base material.

**Step 6:** Using a wrench or drill, rotate the screw until the head of the concrete screw is tight against the surface of the fixture. Make sure that the screw is not over-torqued as this may strip the threads in the base material and cause it to spin in the hole.

**Step 7:** Wipe away any excess silicone or structural adhesive.

**Note: Tapcon® Layout**

2 layouts are acceptable for the 4 Tapcon® screws:

**OPTION 1**



## OPTION 2

